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TRENDS IN EX-VESSEL VALUE AND SIZE COMPOSITION OF REPORTED ANNUAL CATCHES OF PINK SHRIMP FROM THE TORTUGAS FISHERY, 1960–1978[1]

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ABSTRACT Exponential models were used to characterize (1) ex-vessel value (in dollars) per shrimp by size category (count; i.e., number of shrimp per pound, heads off), (2) size composition (expressed as cumulative weight of the catch in pounds, heads off, by size category), and (3) ex-vessel value composition (expressed as cumulative ex-vessel value, in dollars, of the catch by size category) for reported annual catches (inshore and offshore combined) of pink shrimp (*Penaeus duorarum duorarum*) from the Tortugas fishery (statistical areas 1 and 2 combined) from 1960 to 1978. Exponents of the models were used as indices to investigate trends in ex-vessel value per shrimp, in size composition, and in ex-vessel value composition of the annual catches during that period. Both the spread in ex-vessel value per shrimp among size categories and the size of shrimp in the annual catches increased from 1960 to 1978. Also, the proportion of the ex-vessel value made up of shrimp of larger sizes increased from 1960 to 1978. This approach to analysis of catch statistics can be used to monitor the fishery, and the results can be compared with changes that may be brought about by permanently closing the Tortugas shrimp sanctuary in 1981, as proposed by the Gulf of Mexico Fishery Management Council in the fishery management plan for the shrimp fishery of the Gulf of Mexico.

INTRODUCTION

The fishery management plan for the shrimp fishery of the Gulf of Mexico, prepared by the Gulf of Mexico Fishery Management Council (GMFMC 1980), recommended permanently closing the Tortugas shrimp sanctuary (Figure 1) off southern Florida to all shrimping. The purpose of the closure is to protect small pink shrimp (*Peneaus duorarum duorarum*) so that they might survive and grow to sizes larger than 69 count (refers throughout this paper to number of shrimp per pound, with heads removed) before harvest. Essentially, this measure would reestablish most of the original Tortugas shrimp nursery which, until recently, had served as a sanctuary for pink shrimp recruited to the Tortugas and Sanibel shrimping grounds off southern and southwestern Florida, respectively. The management plan also encouraged the State of Florida to allow fishermen to retain all shrimp (including those of 69 count or smaller) caught in the open waters of the fishery conservation zone (FCZ), the area under federal jurisdiction beginning at the outer limit of Florida's territorial sea and extending 200 miles from shore.

Growth and mortality estimates by Lindner (1966) and Berry (1970) indicated that pink shrimp yield would be maximized if harvest were limited to shrimp larger than 70 count. However, Florida's minimum legal size limit of 70 count may have led to the discarding of large quantities of undersized pink shrimp caught in the FCZ. Thus, there is considerable interest on the part of the fishing industry, the State of Florida, the GMFMC, the National Marine Fisheries Service (NMFS), and fisheries scientists regarding the potential impacts of permanently closing the Tortugas shrimp sanctuary on the yield of pink shrimp from the Tortugas fishery.

Apart from changes in yield caused by annual fluctuations in recruitment, changes in yield that may result from the closure probably will be accompanied by changes in size composition of the catch. Mean size is a simple criterion used for assessing status of an exploited stock (Henderson 1972, Ricker 1975). An increase in average size of individuals could indicate a decrease in mortality (usually equated with a decrease in fishing mortality) or an increase in growth. A decrease in average size might be brought about by retention of large quantities of small shrimp that formerly were discarded. Socioeconomic factors affecting strategies of fishing, culling of the catch, and marketing of the landings also could influence the size composition of the catch.

Caillouet et al. (1980) developed a simple exponential model to characterize the size composition (expressed as the cumulative percentage of weight of catch by size category) of reported annual catches of shrimp. Using a logarithmic transformation, they converted the model to one of a straight line, the slope (= exponent of the exponential model) of which was estimated by linear regression analysis. The model was used as an index to investigate fluctuations and trends in size composition of brown shrimp (*P. aztecus*) and white shrimp (*P. setiferus*) catches in Texas and Louisiana from 1959 to 1976. Caillouet and Koi (1980) modified the model by expressing size composition in terms of cumulative weight of catch by size category, instead of cumulative percentage of weight by size category. They used the modified model to investigate trends in size composition of the reported annual landings of brown, pink, and white shrimp from the Gulf and southeast coast fisheries of the United States from 1961 to 1977. They recognized

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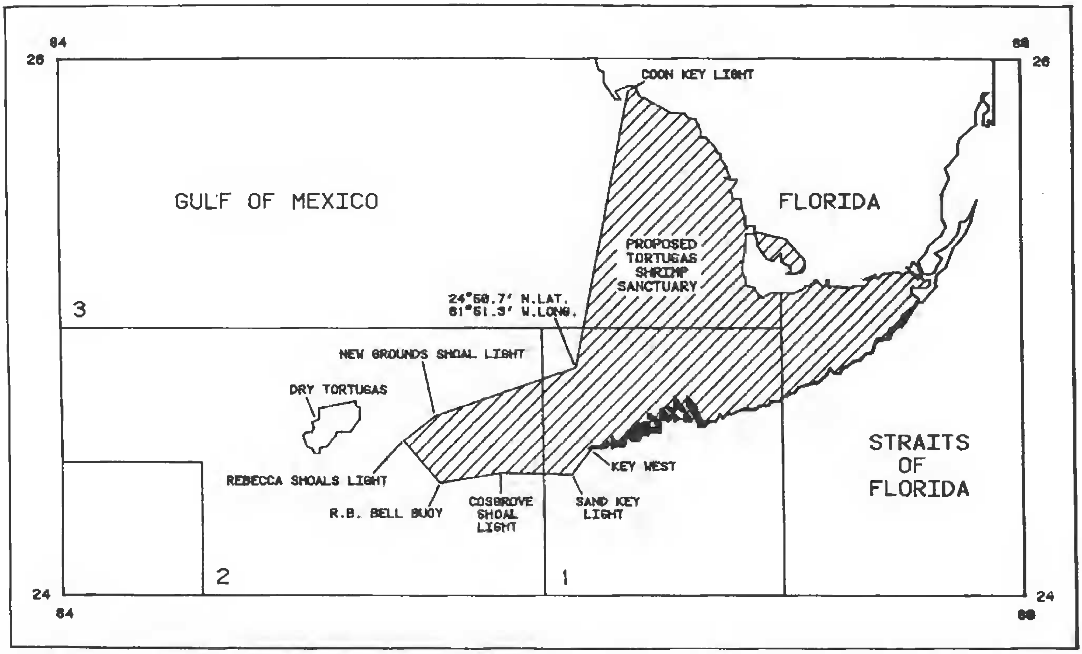

Figure 1. Boundaries of the Tortugas fishery (statistical areas 1 and 2 combined), the Tortugas shrimp sanctuary, the territorial sea, and the fishery conservation zone off south Florida (adapted from GMFMC 1980).

that the exponent of the model would be unaffected by the modification. They also used exponential models to investigate trends in the ex-vessel value per shrimp by size category and the ex-vessel value composition of the annual landings, and conducted simulations to predict the results of continued trends. Similar analyses were performed by Caillouet and Koi (1981) on reported May-August catches of brown and white shrimp from the Texas, Louisiana, Mississippi, and Alabama coasts from 1960 to 1978. The effect of shrimp size on the ex-vessel value of the catch has also been recognized by Neal (1967), Griffin et al. (1974), Griffin and Nichols (1976), and Griffin et al. (1976).

The NMFS has responsibility for monitoring the impacts of the permanent closure of the Tortugas shrimp sanctuary. The purposes of this paper are to propose a procedure for monitoring the Tortugas pink shrimp fishery based on the methods of Caillouet and Koi (1980), and to use their methods to investigate trends in ex-vessel value per shrimp by size category, size composition, and ex-vessel value composition of reported annual catches from 1960 to 1978. This approach then can be used as one means of assessing the impacts of permanently closing the Tortugas shrimp sanctuary and of retaining small shrimp harvested within the FCZ.

DESCRIPTION OF DATA

Annual summaries of the weight and ex-vessel value of the reported catches were compiled from data files available from the NMFS, Southeast Fisheries Center (SEFC), Technical and Information Management Services (TIMS), Miami, Florida. The weight of the reported annual catches (inshore and offshore combined) of pink shrimp from the Tortugas fishery (statistical areas 1 and 2 combined, Figure 1) was expressed in pounds (heads off), and the ex-vessel value in dollars, by size category (< 15, 15–20, 21–25, 26–30, 31–40, 41–50, 51–67, and ⩾ 68 count, and "pieces") and by year (1960–1978). The "pieces" category represented parts of shrimp tails that could not be assigned to a numerical size category. Data for 1979 and 1980 were not available at the time of this writing.

English rather than metric units are used throughout this paper because they have been used historically, and information would be lost in their conversion to metric units. The reported annual catch represents that part of the actual annual catch reported by the NMFS, SEFC, TIMS, or its predecessor, the Bureau of Commercial Fisheries (BCF), U.S. Fish and Wildlife Service (USFWS).

ANALYSES AND RESULTS

Reported Annual Catches

Reported annual catches of pink shrimp from the Tortugas fishery showed a gradual downward trend from 1960 to 1978, while the reported ex-vessel value of these catches showed an upward trend (Figure 2). However, the ex-vessel value was not adjusted to account for inflation.

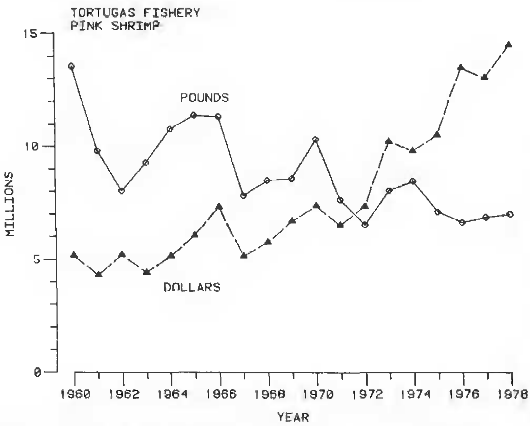

Figure 2. Weight (millions of pounds, heads off) and ex-vessel value (millions of dollars) of reported annual catches (inshore and offshore combined) of pink shrimp from the Tortugas fishery (statistical areas 1 and 2 combined), 1960–1978.

Annual Ex-vessel Value per Shrimp by Size Category

We divided dollars by pounds in each of seven size categories (15–20, 21–25, 26–30, 31–40, 41–50, 51–67, and ⩾68 count) to obtain annual average ex-vessel value per pound by size category for each year. Next, we divided annual average ex-vessel value per pound in each of the seven size categories by the lower limit, C, of the respective size categories to obtain annual average ex-vessel value per shrimp, V, in each of the seven size categories for each year. Because lower limits of size categories were used as divisors, the calculated value per shrimp was the highest that could be obtained from the data for each size category.

The following exponential model described the relationship between V_i and C_i for each year:

$$\hat{V}_i = a\,(\exp bC_i) \qquad (1)$$

where V_i = annual average ex-vessel value per shimp for the ith size category, C_i = lower limit (count) of the ith size category (C_1 = 15, C_2 = 21, C_3 = 26, C_4 = 31, C_5 = 41, C_6 = 51, and C_7 = 68), and i = 1, 2, . . . , 7. The logarithmic form of the exponential model was used to estimate parameters a and b by linear regression (Table 1). The high coefficients of determination, r^2, indicated that the fits of the straight lines to the points were very close. All slopes, b, were negative, reflecting the decrease in ex-vessel value per shrimp with increase in count (decrease in size). Note that the straight lines were obtained by a double transformation. The value per shrimp was transformed to natural logs, and the weight per shrimp (in pounds) was transformed to its reciprocal, count.

TABLE 1.

Relationship between transformed ex-vessel value (dollars) per shrimp, lnV, and count, C, for reported annual catches (inshore and offshore combined) of pink shrimp from the Tortugas fishery (statistical areas 1 and 2 combined), 1960–1978.*

Year	a	b	r^2
1960	0.08055	−0.05105	0.992
1961	0.07934	−0.04703	0.982
1962	0.10499	−0.04549	0.991
1963	0.11350	−0.05259	0.987
1964	0.10157	−0.05134	0.996
1965	0.09966	−0.04762	0.989
1966	0.10238	−0.04363	0.985
1967	0.12016	−0.04807	0.990
1968	0.14652	−0.05343	0.990
1969	0.16510	−0.05231	0.990
1970	0.16200	−0.05304	0.994
1971	0.22503	−0.06109	0.997
1972	0.31373	−0.06409	0.996
1973	0.25167	−0.05121	0.999
1974	0.28464	−0.05747	0.975
1975	0.31197	−0.05378	0.995
1976	0.51520	−0.05762	0.997
1977	0.44743	−0.05526	0.981
1978	0.40966	−0.05079	0.979

*Relationship was based on the linear regression of lnV on C, where V = annual average ex-vessel value per shrimp in each of seven size categories, C = lower limit (count) of each of the seven size categories, ln(a) = intercept, b = slope, and r^2 = coefficient of determination; all slopes, b, were significantly different from 0 at the 99% level of confidence, and the high r^2 values indicated very good fits of the lines to the data points.

Lower limits, rather than midpoints or upper limits of the seven size categories, were used in constructing model 1 because the size categories had unequal intervals, and an upper limit could not be determined for the ⩾68 category. A lower limit of zero for the <15 size category was not realistic, and that category represented only a small fraction (⩽ 1%) of the reported annual catches of pink shrimp from the Tortugas fishery. Therefore, the < 15 size category was excluded from model 1. Also excluded was the category "pieces," which represented parts of shrimp tails, assuming it represented the other size categories in proportion to their relative contributions to the catch. The constant, a, reflected the elevation of the straight line, which was influenced in part by our use of lower limits of size categories and exclusion of the < 15 size category in fitting the straight line. The slope, b, of the straight line is a simple index of the spread in ex-vessel value per shrimp among the seven size categories; i.e., the ex-vessel price structure.

There was a significant downward trend in b from 1960 to 1978 (Tables 1 and 2). This trend indicated that the differences in value per shrimp among the size categories increased with time; i.e., the value per shrimp increased more rapidly for larger shrimp than for smaller shrimp from

1960 to 1978. Whitaker (1973) also observed an increase in price spread between large and small "southern" shrimp during the period from 1957 to 1971.

TABLE 2.

Trends in ex-vessel value (dollars) per shrimp by size category, in cumulative catch (pounds, heads off) by size category, and in cumulative ex-vessel value (dollars) of catch by size category for reported annual catches (inshore and offshore combined) of pink shrimp from the Tortugas fishery (statistical areas 1 and 2 combined) from 1960 to 1978 (based on data in Tables 1, 3, and 4).

	For ex-vessel value per shrimp by size category	For cumulative catch by size category	For cumulative ex-vessel value of catch by size category
Trends*	−0.0005†	−0.0009‡	−0.0012‡
Trend coefficients of determination	0.303	0.346	0.364

*Represent slopes of the linear regressions of b, d, and h, respectively, on x, where x is the last two digits of each year, 1960–1978.
†Indicates that the trend (slope) was significantly different from 0 at the 95% level of confidence.
‡Indicates that the trend (slope) was significantly different from 0 at the 99% level of confidence.

Annual Cumulative Catch by Size Category

We calculated the cumulative weight, P, of the catch in each of the same seven size categories for each year. Catch by size category was cumulated starting with the size category of smallest shrimp (highest count, ⩾ 68), and continuing toward the size category of largest shrimp (lowest count, 15–20).

The following exponential model described the relationship between P_i and C_i for each year:

$$\hat{P}_i = c\,(\exp dC_i) \quad (2)$$

where P_i = cumulative weight of catch in the ith size category. The logarithmic form of the exponential model was used to estimate parameters c and d by linear regression (Table 3). The coefficients of determination were high indicating close fits of the lines to the points. All slopes, d, were negative, which reflected the construction of model 2 by cumulating catch from small-shrimp to large-shrimp size categories. These slopes, d, would have been the same had they been calculated by the method of Caillouet et al. (1980).

The constant, c, reflected the elevation of the straight line and the magnitude of the annual catch, but c was influenced by our use of lower limits of size categories and exclusion of the < 15 size category in fitting the straight line. The slope, d, of the straight line is a simple index of the size composition of the annual catch.

There was a significant downward trend in d from 1960 to 1978 (Tables 2 and 3). This indicated that the size of shrimp in the reported annual catches increased from 1960 to 1978.

TABLE 3.

Relationship between transformed cumulative weight (pounds, heads off) of catch, lnP, and count, C, for reported annual catches (inshore and offshore combined) of pink shrimp from the Tortugas fishery (statistical areas 1 and 2 combined), 1960–1978.*

Year	c	d	r^2
1960	28,961,850	−0.03542	0.947
1961	16,893,678	−0.02889	0.986
1962	19,594,706	−0.04238	0.952
1963	17,562,210	−0.02974	0.950
1964	21,648,787	−0.03264	0.941
1965	24,949,641	−0.03586	0.931
1966	26,482,905	−0.03863	0.924
1967	21,646,839	−0.04588	0.904
1968	26,254,291	−0.05073	0.904
1969	24,944,402	−0.04799	0.891
1970	23,114,946	−0.03684	0.898
1971	21,252,179	−0.04797	0.881
1972	22,106,008	−0.05647	0.852
1973	27,914,589	−0.05364	0.826
1974	27,500,370	−0.05349	0.881
1975	19,683,081	−0.04593	0.857
1976	18,398,874	−0.04559	0.848
1977	17,051,010	−0.04233	0.878
1978	15,703,277	−0.03979	0.924

*Relationship was based on the linear regression of lnP on C, where P = cumulative weight of annual catch in each of seven size categories, C = lower limit (count) of each of the seven size categories, ln(c) = intercept, d = slope, and r^2 = coefficient of determination; all slopes, d, were significantly different from 0 at the 99% level of confidence, and the high r^2 values indicated very good fits of the lines to the data points.

Annual Cumulative Ex-vessel Value of Catch by Size Category

We calculated the cumulative ex-vessel value, D, of the catch in each of the same seven size categories for each year. Ex-vessel value of catch was cumulated starting with the size category of smallest shrimp and continuing toward the size category of largest shrimp.

The following exponential model described the relationship between D_i and C_i for each year:

$$\hat{D}_i = g\,(\exp hC_i) \quad (3)$$

where D_i = cumulative ex-vessel value of catch in the ith size category. The logarithmic form of the exponential model was used to estimate parameters g and h by linear regression (Table 4). Close fits of the lines to the points were indicated by the high coefficients of determination. All slopes, h, were negative, which reflected the construction of model 3 by cumulating ex-vessel value of catch from small-shrimp to large-shrimp size categories.

TABLE 4.

Relationship between transformed cumulative ex-vessel value (dollars) of catch, lnD, and count, C, for reported annual catches (inshore and offshore combined) of pink shrimp from the Tortugas fishery (statistical areas 1 and 2 combined), 1960–1978.*

Year	g	h	r^2
1960	14,791,896	−0.04965	0.953
1961	9,023,023	−0.04032	0.988
1962	16,035,571	−0.05418	0.956
1963	11,014,906	−0.04335	0.958
1964	14,248,184	−0.04797	0.942
1965	16,841,893	−0.04747	0.938
1966	20,560,247	−0.04783	0.934
1967	18,349,264	−0.05825	0.919
1968	24,312,471	−0.06668	0.927
1969	26,218,347	−0.06296	0.916
1970	21,866,361	−0.05150	0.924
1971	28,397,169	−0.07106	0.899
1972	41,023,269	−0.08218	0.872
1973	49,716,628	−0.06940	0.850
1974	42,427,615	−0.07076	0.934
1975	43,790,173	−0.06451	0.858
1976	53,794,404	−0.06424	0.886
1977	41,799,294	−0.05768	0.925
1978	39,534,727	−0.05277	0.959

*Relationship was based on the linear regression of lnD on C, where D = cumulative ex-vessel value of catch in each of seven size categories, C = lower limit (count) of each of the seven size categories, ln(g) = intercept, h = slope, and r^2 = coefficient of determination; all slopes, h, were significantly different from 0 at the 99% level of confidence, and the high r^2 values indicated very good fits of the lines to the data points.

The constant, g, reflected the elevation of the straight line and the magnitude of the ex-vessel value of the annual catch, but g was influenced by our use of lower limits of size categories and exclusion of the < 15 size category in fitting the straight line. The slope, h, of the straight line is a simple index of the ex-vessel value composition of the annual catch.

There was a significant downward trend in h from 1960 to 1978 (Tables 2 and 4). This indicated that the proportions of the ex-vessel value of the catch represented by the size categories of larger shrimp increased from 1960 to 1978.

Size Composition and Annual Catch

There was no significant correlation (at the 95% level of confidence) between the weight of the annual catch (including "pieces," Figure 2), and the annual levels of d (Tables 3 and 5). A lack of correlation would be expected if another factor (e.g., recruitment) played a larger role than variations in size composition in determining weight of the annual catch of shrimp.

TABLE 5.

Linear regressions of ln(a) on b, and of weight (in millions of pounds, heads off) of annual catch on d, for reported annual catches (inshore and offshore combined) of pink shrimp from the Tortugas fishery (statistical areas 1 and 2 combined), 1960–1978 (based on data from Tables 1 and 3).

	For ln(a) on b	For annual catch* on d
Slope	−77.035†	91.977
Intercept	−5.7697	12.5611
Coefficient of determination	0.428	0.170

*Expressed in millions of pounds (Figure 2). Includes "pieces."
†Indicates that the slope was significantly different from 0 at the 99% level of confidence.

Simulations

Models 1 and 2 provided information useful in simulating the impacts of further changes in ex-vessel price structure and size composition of the annual catches. Our simulations were based upon the hypothesis that the observed trends (Table 2) would continue, at least for a few years beyond 1978, were it not for the permanent closure of the Tortugas shrimp sanctuary. We conducted simulations to estimate what the average ex-vessel value per pound of past annual catches of pink shrimp would have been for selected levels of b, to explore the possible consequences of concurrent changes in size composition (as expressed by d) and ex-vessel price structure (as expressed by b).

Because there was a significant inverse relationship between ln(a) and b (Table 5), we were able to estimate parameter a for selected levels of parameter b, to simulate V_i in model 1. We then calculated the corresponding ex-vessel value per pound by size category from the simulated V_i. We used the simulated ex-vessel value per pound for the 15–20 size category as an approximation (minimum) of the ex-vessel value per pound for the < 15 size category. We then multiplied the simulated ex-vessel value per pound in each size category (including the < 15 size category) by the reported pounds caught in each size category to simulate the ex-vessel value of the catches in each size category for each selected level of b and for each year. Pounds caught in the size category "pieces" were excluded from these calculations. The resulting values were summed over size categories to simulate annual ex-vessel value of shrimp catches (pieces excluded) for each level of b and for each year. The simulated annual ex-vessel value was then divided by the reported annual catch (pieces excluded) to obtain simulated annual average ex-vessel value per pound for each level of b and for each year. Straight lines were fitted to the simulated annual average ex-vessel value per pound for each level of b by linear regression (Table 6, Figure 3).

An increase in size of shrimp in the catch (as indicated by a decrease in d), coupled with an increase in price spread among size categories (as indicated by a decrease in b), resulted in a pronounced increase in the annual average ex-vessel value per pound for pink shrimp catches from the Tortugas fishery (Figure 3). Decreases in b produced greater increases in simulated annual average ex-vessel value per pound than did equivalent decreases in d.

TABLE 6.

Linear regressions of simulated average ex-vessel value (dollars) per pound (heads off) on d for reported annual catches (inshore and offshore combined) of pink shrimp from the Tortugas fishery (statistical areas 1 and 2 combined), 1960–1978, for selected levels of b (based on data from Tables 1, 3, and 5).

	b*			
	−0.04	−0.05	−0.06	−0.07
Slope	−1.3908†	−3.0989†	−6.0663†	−11.238†
Intercept	0.4609	0.6449	0.9219	1.3426
Coefficient of determination	0.854	0.788	0.715	0.648

*Levels of b selected for the simulations encompass as well as extend the observed range in b (see Table 1).

†Indicates that the slope was significantly different from 0 at the 99% level of confidence.

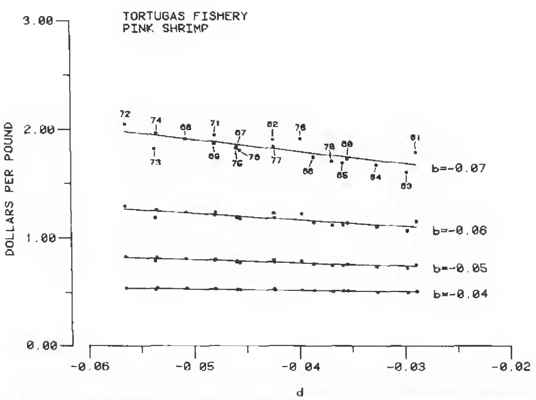

Figure 3. Simulated average ex-vessel value (dollars) per pound (heads off) for selected levels of b, the price structure index, over the range of d, the size composition index, for reported annual catches (inshore and offshore combined) of pink shrimp from the Tortugas fishery (statistical areas 1 and 2 combined), 1960–1978 (based on data from Tables 1, 3, and 5). Lines fitted by linear regression (see Table 6).

DISCUSSION

The extent to which the inclusion of unreported catches would have changed our results and conclusions cannot be determined. We assume that the bulk of the actual catches of pink shrimp from the Tortugas fishery was represented by the reported catches. Discarded undersized shrimp (GMFMC 1980) and shrimp landings sold to bait dealers probably constituted most of the unreported portion of the actual catches (T. J. Costello, NMFS, Miami, Florida, personal communication). A small part of the unreported portion of the actual catches also was made up of catches by foreign fishing craft prior to 1976, and of landings by recreational fishermen. Because the magnitude of the unreported portion of the actual catches was not known, size composition and ex-vessel value composition of the reported catches could be different from the size composition and ex-vessel value composition of the actual catches of pink shrimp from the Tortugas fishery. Furthermore, errors of misclassification of catches by size category occur as an outgrowth of differences in shrimp grading practices ("box" grading versus "machine" grading). However, the extent of such misclassification errors is unknown, as is their effect on size composition of the reported catches.

The trend of increase in ex-vessel price spread among size categories of shrimp, coupled with the trend of increase in size of shrimp in the catches, produced an even more pronounced trend of change in the ex-vessel value composition of the catches (Table 2). This helps explain why the ex-vessel value of the annual catches increased while the weight of the catches decreased from 1960 to 1978 (Figure 2). Inflation also accounted in part for the increase in ex-vessel value of the annual catches. While we did not determine the overall effects of inflation on the increase in ex-vessel value of the annual catches, our results clearly showed that this increase occurred partly because the rate of inflation in ex-vessel price was greater for large than for small shrimp. The results of our simulations (Figure 3) further illustrated the effects of concurrent changes in price spread and size composition.

Hooker (1972) and Toevs and Johnson (1978) suggested that the price of a given size category of shrimp depended on its relative abundance within the supplies available to the market. Hooker (1972) recognized that imported shrimp and cold storage holdings might influence size composition of available shrimp supplies, but postulated that the price spread was influenced more by the size composition of current landings. Size composition of the reported catches was determined by the combined effects of shrimp growth and mortality (natural and fishing), shrimp discarding, gear selectivity, shrimp grading practices, and catch sampling and reporting procedures. Finally, the price spread probably was influenced to some extent by the realtive demand for shrimp of various sizes.

In exploring possible causes of annual fluctuatons in size composition of catches (Table 3), we considered the influences of major changes in regulations concerning the Tortugas fishery during the period from 1960 to 1978. For this purpose, we used an historical review of Florida legislation relating to management of the Tortugas fishery (Costello 1979). House Bill No. 2475, enacted in June 1961, redefined the geographical limits of the Tortugas shrimp beds, changed the size limits governing the opening and closing of the controlled area from 50 to 60 count, and established nursery areas within which no shrimping was allowed, except for live bait. Enactment of these regulations, intended to protect small shrimp, was followed by an increase in size of shrimp in the catch in 1962.

In 1963, the size composition was similar to that of 1961 (Table 3). In 1964, a trend of increasing size of shrimp in the catch began and continued through 1968. In 1969 and 1970, there again was a shift toward decreasing size of shrimp in the catch. We have no explanation for these changes.

Senate Bill No. 1370, enacted in July 1970, defined new boundaries for the Tortugas shrimp beds and prohibited shrimping, except for live bait, in those beds after July 1, 1970. It also repealed the size limit restriction governing the opening and closing of the controlled area, because the limit was no longer needed in the context of the redefinition of the Tortugas shrimp beds and the prohibition of shrimping in those beds. These regulations were intended to further restrict the catch of small shrimp. In 1971 and 1972, the size of shrimp in the catch increased (Table 3). Senate Bill No. 241, enacted in October 1972, made minor changes covering penalties for violations of regulations.

In 1973, the shrimping industry began to feel the effects of a critical fuel shortage. Increases in the cost of fuel may have encouraged shrimping closer to home ports. In 1973 and 1974, the size of shrimp in the catch decreased (Table 3). Senate Bill 505, enacted in April 1974, redescribed the boundaries of the Tortugas shrimp beds in unambiguous terms, as a response to previous court actions and to facilitate enforcement of regulations. However, there was limited enforcement of the seasonal closure of the controlled area to shrimping through 1978 (T. J. Costello, personal communication). In 1975, there was a substantial decrease in size of shrimp in the catch, and the trend of decreasing size continued through 1978. It remains to be determined what changes, if any, took place in 1979 and 1980, and what the impacts of permanently closing the Tortugas nursery area in 1981 may be on the weight, size composition, and ex-vessel value of the annual catch.

While the observed shifts in the size composition of the catch may have been related to historical changes in the regulations affecting the temporal-spatial distribution of fishing effort, it also could be argued that the changes in size composition may have been related to changes in quantity of fishing effort. Our analysis does not distinguish biological from socioeconomic influences on size composition of the catch, so any conclusions as to cause and effect are speculative at this time.

The trend of increase in ex-vessel price spread among size categories of shrimp probably reflects trends in supply versus demand for shrimp of various sizes in the market. Differences in costs of harvesting shrimp close to ports versus farther from ports, as well as other factors, also may have affected the supplies of shrimp of various sizes and, therefore, the ex-vessel price spread. Further investigations of costs, supply and demand, inflationary effects, other economic factors, and changes in fishing effort are needed to explain the trends we observed (see Christmas and Etzold 1977, GMFMC 1980).

Future analyses similar to ours, based on additional catch statistics as they become available, will be one means of monitoring the Tortugas fishery. If the closure of the Tortugas shrimp sanctuary is effective in saving significant quantities of small pink shrimp to grow to larger sizes before harvest, an increase should occur in size of shrimp in the annual catch. On the other hand, if Florida allows shrimp ≥70 count caught in the FCZ to be retained rather than discarded by fishermen, and if the fishermen land and market significant quantities, that might decrease the size of shrimp in the annual catch.

As expected, our simulations show that the average ex-vessel value of a given weight of catch increases substantially when an increase in ex-vessel price spread among size categories is coupled with an increase in size of shrimp in the catch (Figure 3). This is reflected by the observed trend of increase in ex-vessel value of the annual catch despite the trend of decrease in weight of the catch (Figure 2), although the ex-vessel value of the catch also is influenced by inflation. However, at some point, further decrease in total weight of the annual catches may override the influences of increasing price spread among size categories and inflation. Thus, the ex-vessel value of the catch may reach an upper limit at some point when losses through natural mortality begin to override the increase in size of shrimp in the catch, the increase in the price spread between large and small shrimp, and the effects of inflation.

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REFERENCES CITED

Berry, R. J. 1970. Shrimp mortality rates derived from fishery statistics. *Proc. Gulf Caribb. Fish. Inst.* 22:66–78.

Caillouet, C. W. & D. B. Koi. 1980. Trends in ex-vessel value and size composition of annual landings of brown, pink, and white shrimp from the Gulf and south Atlantic coasts of the United States. *Mar. Fish. Rev.* 42(12):18–27.

______. 1981. Trends in ex-vessel value and size composition of reported May–August catches of brown and white shrimp from the Texas, Louisiana, Mississippi, and Alabama coasts, 1960–1978. *Gulf Res. Rept.* 7(1):59–70.

Caillouet, C. W., F. J. Patella & W. B. Jackson. 1980. Trends toward decreasing size of brown shrimp, *Penaeus aztecus*, and white shrimp, *Penaeus setiferus*, in reported annual catches from Texas and Louisiana. *Natl. Mar. Fish. Serv., Fish. Bull.* 77(4): 985–989.

Christmas, J. Y. & D. J. Etzold (eds.). 1977. *The Shrimp Fishery of the Gulf of Mexico United States: A Regional Management Plan.* Technical Report Series No. 2, Gulf Coast Research Laboratory, Ocean Springs, MS. 128 pp.

Costello, T. J. 1979. A historic review of State of Florida regulations relating to the Tortugas pink shrimp fishery and rationale underlying these regulations. National Marine Fisheries Service, SEFC, Miami, Florida. 8 pp. (unpublished).

Griffin, W. L., R. D. Lacewell & W. A. Hayenga. 1974. Estimated costs, returns, and financial analysis: Gulf of Mexico shrimp vessels. *Mar. Fish. Rev.* 36(12):1–4.

Griffin, W. L. & J. P. Nichols. 1976. An analysis of increasing costs to Gulf of Mexico shrimp vessel owners: 1971–1975. *Mar. Fish. Rev.* 38(3):8–12.

Griffin, W. L., N. J. Wardlaw & John P. Nichols. 1976. Economic and financial analysis of increasing costs in the Gulf shrimp fleet. *Nat. Mar. Fish. Serv., Fish. Bull.* 74(2):301–309.

Gulf of Mexico Fishery Management Council (GMFMC). 1980. Fishery management plan for the shrimp fishery of the Gulf of Mexico. *Fed. Reg.* 45(218):74190–74308.

Henderson, F. 1972. The dynamics of the mean-size statistic in a changing fishery. *FAO Fish. Tech. Paper* No. 116. 16 pp.

Hooker, P. T. 1972. Systems analysis of U.S. management strategies in the Gulf of Mexico shrimp industry. Ph.D. dissertation. University of Florida, Gainesville, FL, 185 pp.

Lindner, M. J. 1966. What we know about shrimp size and the Tortugas fishery. *Proc. Gulf Caribb. Fish. Inst.* 18:18–26.

Neal, R. A. 1967. An application of the virtual population technique to penaeid shrimp. Pages 264–272 in *Proceedings of the 21st Annual Conference, Southeastern Association of Game and Fish Commissioners.* Sept. 24–27, 1967, New Orleans, LA.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. *Bull. Fish. Res. Board Can.* 191. 382 pp.

Toevs, A. L. & D. B. Johnson. 1978. *Economic Characterization of the U.S. Gulf of Mexico Shrimp Fishery.* Louisiana State University, Center for Wetland Resources, Baton Rouge, LA. 168 pp.

Whitaker, D. R. 1973. The U.S. shrimp industry: Past trends and prospects for the 1970's. *Mar. Fish. Rev.* 35(5–6):23–30.